A Layman's Guide to the CREWS Network

by

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A Brief Explanation

At the National Oceanic and Atmospheric Administration's (NOAA) Atlantic Oceanographic and Meteorological Laboratory (AOML), in Miami, Florida, environmental data are currently (or will be by 2007) acquired from meteorological and oceanographic monitoring stations at remote coral reef areas throughout the world (e.g., the Florida Keys, the Bahamas, Hawaii, U.S. Virgin Islands, Puerto Rico, American Samoa, etc.) via a satellite data archival site at Wallups Island, Virginia. The data are collected at the sites continuously then transmitted hourly. Oceanographic instruments measuring sea temperature and salinity, together with meteorological instruments for measuring wind speed, wind gust, wind direction, air temperature, dew point, and barometric pressure are maintained by cooperating federal agencies or universities. At these remote coral reef sites there are many physical, chemical, and biological events of interest and concern to personnel of marine parks and sanctuaries, marine biologists, oceanographers, fishermen, and divers. Some of these events would be observable if it were possible to continuously be present at the remote site of interest, or if instrumentation could monitor the remote site and the observer could in turn routinely monitor the output of the instrumentation. Except in very critical cases, however, large volumes of data are generated by the instruments at these sites and no one has the time to look at every printout of data from every station, every day, seven days a week. Thus, an automated system that monitors the meteorological and oceanographic parameters and produces specialized alerts of specific events, as indicated by prescribed or abnormal ranges, or combinations of parameters, was developed to facilitate timely observation and interpretation of data for the benefit of coral reef researchers and managers.. This combined software and hardware system, originally patterned after the SEAKEYS network in the Florida Keys, is called the Coral Reef Early Warning System (CREWS).

CREWS produces automated electronic mail and World-Wide Web alerts when conditions are thought to be conducive to, or predictive of, coral bleaching, which occurs under conditions of environmental stress. This suite of expert systems (see explanation below) represents a first step in the construction of a larger coral reef specific expert system, and the first of many applications for marine environmental monitoring. Although the primary application is for determining when marine environmental conditions are conducive to coral bleaching, CREWS also serves as a model development tool for testing hypotheses regarding other environmental phenomena, such as spawning and migration of fish and invertebrates. Models regarding the effects of environmental factors are represented as a set of rules. Data captured in near real-time drive the rule-based system to produce predictions and alerts, which are in turn checked against actual observations in nature to evaluate the effectiveness of the models represented by the rule set. The rules are then changed to obtain better predictive models, and thus lend decision support to sanctuary managers and provide researchers enough warning to allow them to travel to the site and study the phenomenon (e.g., coral bleaching) as it happens. This approach is an important new development in the use of knowledge-based systems to solve environmental problems, as it provides for knowledge synthesis (in the form of data summaries) from any environmental ASCII data stream or table, be it real-time or not.

A Little Deeper Explanation

Expert Systems

Expert systems, or knowledge-based systems, are a branch of artificial intelligence (AI). Artificial intelligence involves the capability of a device such as a computer to perform tasks that would be considered intelligent if they were performed by a human. An expert system is a computer program that attempts to replicate the reasoning processes of experts and can make decisions and recommendations, or perform tasks, based on user input. Knowledge engineers construct expert systems in cooperation with problem domain experts so that the expert's knowledge is available when the expert might not be, and so that the knowledge can be available at all times and in many places, as necessary. Expert systems derive their input for decision making from prompts at the user interface, or from data files stored on the computer. The knowledge base upon which the input is matched is generally represented by a series of IF/THEN statements, called production rules, which are written to approximate the expert's reasoning. The degree of belief the expert has in a conclusion may be represented as a confidence factor (e.g., 0% to 100% confidence), or as a subjective term (e.g., "possibly," "probably," or "almost certainly") in the expert system.

Coral Bleaching

The coral bleaching phenomenon is a complex one, and many causes have been offered in the published literature. High temperatures appear to be the primary stressor; however, researchers have hypothesized other stressors. In almost all bleaching studies, however, examinations into the cause of a bleaching event follow at an appreciable time (usually weeks or months) after the fact. CREWS has been designed to allow researchers to model and further understand the coral bleaching phenomenon before and immediately after it occurs. It screens near real-time incoming wind speed, sea temperature, salinity, transmissometry, photosynthetically active radiation, ultraviolet light and tide level data to determine if conditions are optimal for coral bleaching, depending on which coral bleaching hypothesis is being tested. The expert system provides production rules to model several hypotheses. Thus, the expert system tests whether high temperatures alone are responsible for coral bleaching, or whether other combinations of environmental stressors (e.g., high illumination, abnormal salinities, low tides) appear to be responsible. The expert system has an additional benefit in that it automatically alerts volunteers and researchers of predicted bleaching events so that they can travel to the site for further study. Their feedback enables the knowledge engineer to continue to fine-tune the system, and thus provide validation of the modeled hypotheses, and also enables timely investigation of the developing phenomenon. The expert system outputs, once validated, provided marine sanctuary managers and researchers immediate feedback on one facet of the status or condition of the sanctuary.

CREWS can be extended to monitor additional parameters and prepare alerts to other biological and natural events, which may be important not only to scientists, but to fishermen and divers, as well. Such alerts could include conditions conducive to larval fish (and other animal) survival or death (e.g., extended high or low temperatures and/or salinity), extended duration of clear or turbid water (via transmissometry measurements), phytoplankton or harmful algal blooms (measured indirectly through fluorescence), warm and cold fronts (using air temperature and barometric pressure), local (to the stations) high and low tides (depth sensors at the stations), influx of hypo- or hypersaline waters (salinity measurements), excessive dissolved nutrient encroachment (reflected in sustained high levels of fluorescence, or through nutrient sensors), influx of cool or warm water, and alerts to sudden wind and/or air temperature changes. The coral bleaching expert system will pave the way for the continuation of a larger expert system, because data from all of the monitored environmental parameters are summarized in a format which can be readily utilized for future problem domains. Thus, the coral bleaching expert system serves as an example of the many possibilities for expert system monitoring of multiple physical parameters in the marine environment, a task attempted or contemplated by others, but never before accomplished.

Barriers, Difficulties and Issues

Some of the significant problems to setting up a data collection network alone (not to mention the expert system knowledge engineering) include the following:

- The financial outlay to construct just one station can be over US $150,000 (but price depends on many factors). This could include the cost of a ship to drive the pilings upon which a station will sit; moreover, the logistics of scheduling the ship during perfectly calm weather is difficult. Floating platforms are easier and cheaper to construct, but they must be moved to safe harbor in the event of large storms such as hurricanes or typhoons (thus missing the measurement of these important environmental stressors).
- Biofouling of oceanographic instruments occurs in periods of a week to a month, so maintenance of the stations, often in dangerous or stormy conditions, must be continuous if true year-round environmental monitoring must be achieved.
- Permission must be received from the U.S. Coast Guard and the sanctuary to construct the station. Such permission may extremely difficult to come by and may require numerous permits.
- If the site is remote, the data must be sent via satellite. This requires subscribing to an available and appropriate satellite, then implementing a data retrieval system.
- The cost of field support for environmental technicians is appreciable when you consider salaries, boats, trailers, fuel, insurance, supplies and a host of hidden costs.

A computer search of over 100 bibliographic databases revealed that many expert systems have been constructed for maritime purposes and for disciplines related to marine science, but of all these references, none described the use of an expert system to review incoming near real-time data for the purpose of predicting or describing biological events in the ocean or coastal environment. Even if data are forthcoming from such a marine environmental network, the oceanographic environment is an extremely complex one to model. CREWS, however, establishes a framework upon which to add knowledge incrementally, as is the usual case with large expert systems. Once encoded heuristics appear to successfully represent expert knowledge of the environmental event, production rules representing new knowledge for other marine environmental domains can then be added to the system, and further testing can ensue.

Difficulties in the development of the CREWS suite of expert systems included the following areas:

1) *Effectively handling garbled data.* Sooner or later an instrument is bound to malfunction and send garbled data. The expert system checked to see whether the incoming data message was a numeric field; if it was not, it replaced the "value" with a tag to represent a null value. The expert system did not consider values which were null; that is, production rules relying on those parameters would not fire. If garbled data contained all numbers, the expert system noted those numbers as being out of range, if in fact they were. Experience has shown that such occasions are extremely rare, and that garbled numbers within range do not occur for more than two values in a row, thus the expert system is able to identify the occurrence.

2) *Encoding domain knowledge in the expert system shell.* Some meteorological and oceanographic experts were interviewed, and it became apparent that extracting knowledge from them required knowing the correct questions to ask, and how to ask them. These people are busy and so the process had to be designed very efficiently and every effort was made so the expert should feel that his or her answers related directly to the success of the system. It was also necessary to convince them that the expert system was a worthwhile system that could save them time or assist them in the long-run.

3) *Discerning environmental changes over several days and within discrete periods.* The approach was to average values of the parameters for eight periods for each day, save these values to system "facts" specific to the days, then treat combinations of the facts with rules in the expert system. The eight periods were termed midnight, predawn, dawn, morning, midday, pre-sunset, sunset, and evening. The day was broken up into these periods for two reasons: 1) the periods reflect distinct times of the day in which environmental phenomena appear to occur in response to combinations of meteorological and oceanographic parameters; and, 2) since some values vary widely throughout the day, having them averaged within periods makes data handling and parameter combinations easier to comprehend. Also, and most importantly, it is often the high or low value of one parameter measured, combined synergistically with a high or low value of another parameter measured, *within a discrete period of time*, that often results in a stress-related response of an organism to the environment. A system or investigation that monitors averages of these values over extended periods of time may miss critical combinations of factors at point sources in time. The present approach of monitoring combinations of environmental parameters in near real-time, together with coral response, has not been undertaken by any other researchers in coral bleaching, so far as this author is aware, but the notion of possible harmful combinations of environmental factors has been conjectured in the literature.

4) *Verification of bleaching events.* The reefs being monitored are remote from AOML, so it is difficult to get timely feedback on whether or not bleaching is actually occurring at the reef in question. Conditions at the different periods of the day, and for different days, were saved as facts to a blackboard system, which were then retrieved at the appropriate time for further analysis. During that

time, production rules representing the various coral bleaching hypotheses were matched against the saved facts and the output stated which hypothesis was being tested. As coral bleaching "alerts" were produced, the locally contracted technicians, who visited the sites, were able to relay feedback and provide verification (or not) of the coral bleaching hypotheses being tested.

5) *Dealing with conflicting models*. Although the preponderance of evidence favors high sea temperatures as being conducive to most incidences of coral bleaching, there is a growing amount of literature that cites the deleterious effects of ultraviolet radiation. Other researchers feel high or low salinities, or combinations of several environmental factors, stress corals into bleaching. The strength of the present expert system is that many of these hypotheses or models were configurable in the expert system, and could be readily reviewed against the incoming data.

The expert system has been and will continue to be of value in helping the experts obtain timely observations. They eventually will be able to refine their coral bleaching models, which can again be reflected in a rewrite of the production rules.

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